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COMPARATIVE ANALYSIS OF ACCESSIBILITY TO PRIMARY ACTIVITY NODES IN PORT-ORIENTED CITIES

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Abstract: This study assesses the accessibility and coverage of primary facilities in Cartagena and Buenaventura, two Colombian port cities that share comparable socioeconomic profiles but exhibit contrasting urban conditions. The aim is to examine how socioeconomic classification shapes equity in access to opportunities, emphasizing the role of territorial configuration in shaping everyday access to essential services. The methodological approach integrates geographic accessibility modelling with detailed spatial analysis of sociodemographic variables, combining travel-time estimations to healthcare, education, and community facilities with the assessment of population distribution and the spatial concentration of infrastructure. This integrated framework allows the identification of territorial inequalities and highlights how urban form and service allocation interact to condition access to basic opportunities. The results show that Buenaventura faces considerably lower accessibility levels, driven by limited road connectivity, fragmented urban development, population dispersion, and a reduced supply of primary facilities, all of which generate persistent structural gaps that constrain social development and diminish quality of life. Cartagena, in contrast, benefits from a more consolidated infrastructure network and a denser distribution of services, despite sharing similar economic constraints, which reveals that disparities are shaped less by port-city status and more by long-term planning trajectories, investment patterns, and institutional capacity. The interpretation of these findings underscores the urgency of adopting equitable territorial planning strategies that respond to the specific needs of each city, promoting more balanced access to essential urban services in development in port-city environments.

Keywords: accessibility, equity, geostatistic, socioeconomic stratification, port cities

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INTRODUCTION

In the contemporary urban context, equitable access to the multiple opportunities offered by the city—such as social, economic, cultural, educational, and environmental services—is deeply conditioned by structural factors such as residential location and household income levels. These conditions determine not only the quality of the immediate environment but also citizens' real ability to move toward places that concentrate goods and services, directly affecting their capacity to fully exercise the right to the city. In this sense, urban space is neither distributed nor experienced homogeneously; on the contrary, it takes shape as a field of social and territorial inequalities.

As noted by Miralles and Cebollada, spatial practices and patterns of daily mobility are strongly shaped by individuals' socioeconomic position, which limits access options to essential facilities for the most vulnerable sectors (Miralles & Cebollada, 2009). This functional and territorial segregation is reinforced by the unequal provision of basic services such as health, education, and transportation, which perpetuates dynamics of exclusion and hinders urban integration. As Villar points out, these gaps translate into inequitable urban conditions in which certain social groups face restrictions on access to fundamental rights—constituting a form of spatial injustice that persists in Latin American cities (Escobar et al., 2024; Villar, 2021).This phenomenon is clearly evident in Colombian cities such as Cartagena and Buenaventura, both of which have a strategic port profile within the national economic system but also display complex and contrasting urban dynamics. Despite sharing similar geographic and functional characteristics, they present profoundly unequal urban realities in terms of infrastructure, social development, and territorial planning (Castro et al., 2015).

In these territories, accessibility to essential urban facilities—such as healthcare, educational centers, security institutions, and recreational areas—varies significantly not only between socioeconomic groups but also across internal geographic zones, marking sharp differences between consolidated urban centers and excluded peripheries (Aristizabal et al., 2023). This disparity directly affects the quality of life of the population, particularly those living in marginalized areas with limited connectivity and scarce state presence. In the case of Buenaventura, limitations in road connectivity, low density of urban

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facilities, and a dispersed residential fabric create a scenario of functional fragmentation, where accessing basic services requires traveling long distances or facing precarious transport conditions. This situation not only reduces urban efficiency but also restricts access to fundamental rights, deepening social exclusion (Angulo & Lerma, 2025; Cabezas, 2025).

Cartagena de Indias, on the other hand, while it also contains vulnerable areas, benefits from a more consolidated system of urban services and a road network with greater coverage, allowing a significant portion of its population to enjoy better conditions of geographic accessibility. Nevertheless, territorial inequalities persist, showing that even in more developed urban contexts, accessibility is not guaranteed equitably (Alvis et al., 2009).

These structural differences between the two cities reflect not only disparities in public investment but also the absence of comprehensive territorial planning policies that guarantee universal access to urban services, making accessibility a key factor in analyzing spatial justice and equity in Colombian urban development.

As a prelude to this study, it is necessary to further understand the concept of accessibility, which has been recognized since the mid-20th century as a central concept in urban and transport planning studies, with direct implications for territorial equity and spatial justice. Hansen's initial definition describes it as the potential of opportunities for interaction (Hansen, 1959), where opportunities refer to valuable destinations in the environment and interaction is materialized in the effective capacity of people to access them. Since then, multiple approaches have expanded this concept, emphasizing its close relationship with urban geography and spatial analysis (Batty, 2009; Portugali, 1980). Several authors have proposed complementary classifications of the term, differentiating between potential accessibility—associated with the probability of reaching a destination—and realized accessibility—linked to the effective use of services (Garrocho & Campos, 2006; Martinez, 2012). These definitions are operationalized through probabilistic functions that consider impedances such as travel time or distance, which are fundamental elements for assessing equitable access to urban opportunities (Reggiani et al., 2011; Wu & Levinson, 2020).

In this research, accessibility is used as a tool for spatial assessment, focusing on average travel time to primary facilities, represented through isochrone maps (Biazzo et al., 2019), which allow for an integrated visualization of the distribution of opportunities within the urban network, facilitating the analysis of coverage and relative location.

Moreover, recent studies highlight that accessibility cannot be evaluated in isolation from the social context. In this sense, variables such as socioeconomic conditions (Bocarejo & Oviedo, 2012) and spatial equity criteria (Saif et al., 2019; Walsh et al., 2017) are integrated, allowing for a more precise identification of the barriers faced by the most vulnerable sectors. Evaluations also incorporate the inclusion of alternative transport modes (Hamidi et al., 2019; Hu et al., 2020), recognizing their role in expanding sustainable urban access. Ultimately, accessibility becomes a key indicator for diagnosing territorial inequalities and guiding fairer urban planning decisions. In this context, the present study aims to evaluate and compare accessibility conditions to primary facilities in Cartagena and Buenaventura—two port cities with contrasting socio-spatial realities—in order to identify structural gaps in access to urban opportunities and their relationship with the socioeconomic classification of the population

MATERIALS AND METHODS

Phase 1. Collection and Structuring of Baseline Information. As the first methodological stage, baseline information was collected regarding the road infrastructure network in mixed transport mode in both cities. This information included variables such as road segment length, average operating speed, direction of traffic flow, topology, and connectivity status. Likewise, data related to primary facilities in both cities were collected, consolidated in Table 1 and shown in the Figure 1. The data were obtained from sources such as OpenStreetMap, the National Administrative Department of Statistics (DANE), the Municipal Governments of Buenaventura and Cartagena, as well as local urban development and mobility plans.

Table 1. Total Facilities (Source: Authors)

Facility	Cartagena	Buenaventura
Health	115	15
Educational	509	64
Recreational	160	32
Security	69	10

Once the information was collected, the road network was structured within a geospatial environment, taking into account both the current operating conditions and the specific limitations of each city in terms of connectivity and network density. For this purpose, ArcMap and TransCAD software were used, which made it possible to organize, refine, and prepare the data for modeling. Figure 1 shows the baseline information collected.

Phase 2. Calculation of Travel Time per Road Segment. Once the transport networks were calibrated, travel times for each road segment were estimated using Equation 1 (Escobar, et al., 2015)

$$tv_x = \left(\frac{length_x}{speed_x}\right) * 60 \tag{1}$$

where tv_x is the travel time of segment x in minutes, based on its length (km) and average speed (km/h). This information made it possible to build a complete matrix of minimum travel times between all road nodes in each city, using TransCAD's Multiple Paths tool, which selects the lowest-cost travel time among the multiple available routes between each origin–destination pair (Dijkstra, 1959). Equation 2 (Self made) shows the selection structure.

$$tvij_{min} = \min(tv_{ij1}, tv_{ij2}, tv_{ij3}, \dots, tv_{ijn}) \quad (2)$$

Where $tvij_{min}$ is the minimum travel time among the *n* available routes between points *i* and *j*.

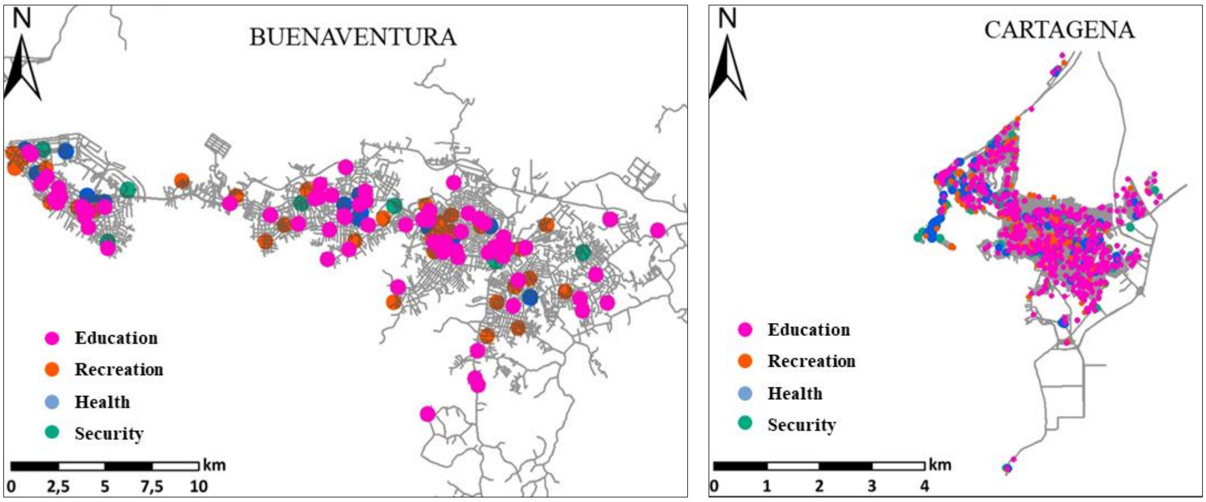

Figure 1. Base Information (Source: Authors)

Phase 3. Construction of Accessibility Curves. After obtaining the minimum travel time matrix, accessibility curves were constructed through interpolation using ArcMap's Geostatistical Wizard tool, generating isochrone curves that allow visualization of the areas with greater and lesser ease of access to urban facilities.

Phase 4. Sociodemographic Coverage Analysis. Once the accessibility curves were obtained, they were cross-referenced with geospatial population layers at the block level, using data from DANE. This analysis made it possible to identify the proportion of the population that accesses basic services within travel times below established thresholds.

The spatial overlay was performed in ArcMap using the Geoprocessing Intersect tool, and the results were organized into cumulative curves (ogives), which illustrate the degree of coverage and the spatial distribution of the benefit

RESULTS AND DISCUSSION

As a result of the geographic accessibility analysis to primary activity nodes in the cities of Buenaventura and Cartagena, Figures 2 and 4 are presented, showing—through a color scale—the estimated travel time required to reach the nearest facility from each point in the territory.

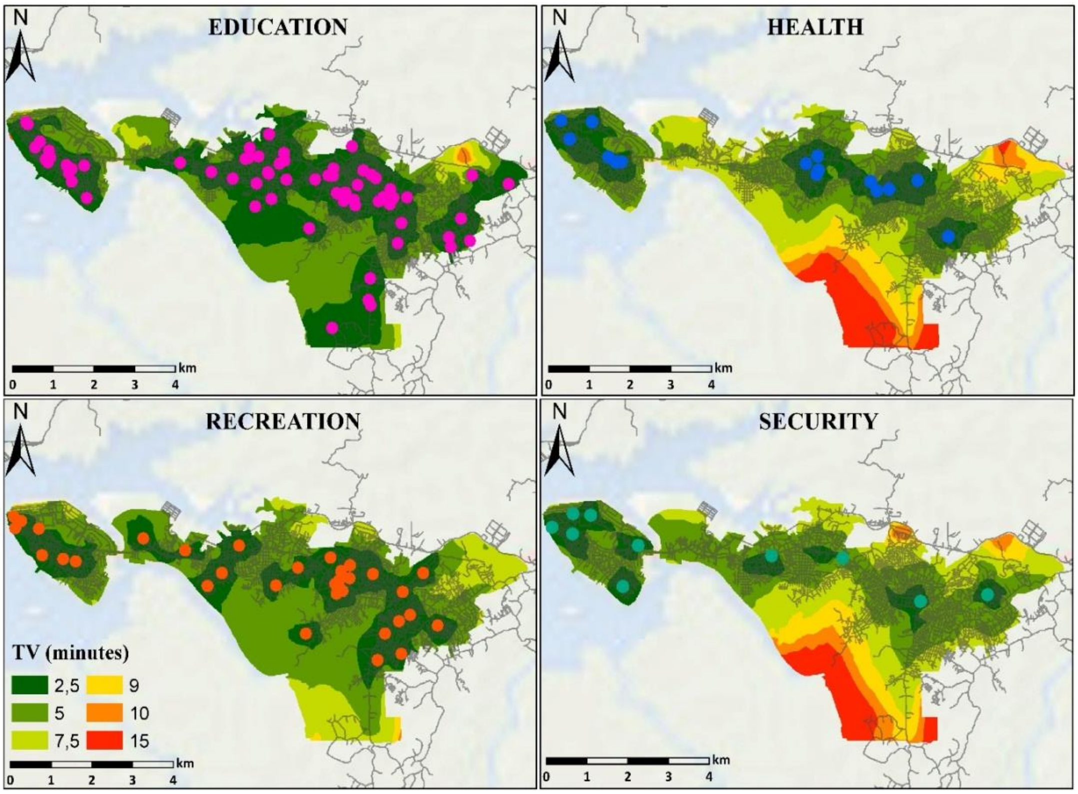

Figure 2. Geographic Accessibility Curves to the Primary Facilities of Buenaventura (Source: Authors)

In Figure 2, corresponding to Buenaventura, it can be observed that a significant portion of the urban area has travel times of less than 5 minutes, particularly toward educational facilities, which display broad territorial coverage. Secondly, recreational facilities also show an acceptable level of accessibility, although with less reach than educational ones.

However, lower accessibility is evident for health and security services, especially in the southern and southwestern sectors of the municipality, where travel times exceed 10 minutes. This pattern reflects an unequal distribution of urban infrastructure, which restricts equitable access to essential services for a considerable portion of the population.

In this regard, the inclusion of new health and security nodes in southern Buenaventura becomes necessary in order to reduce access times, improve service coverage, and advance the guarantee of basic rights for the inhabitants of these areas—particularly those belonging to more vulnerable social groups. Regarding the evaluation of population coverage differentiated by socioeconomic stratification, Figure 3 presents the percentage ogives of coverage for different types of urban facilities as a function of the average travel time required to access these services.

Educational facilities show the highest levels of coverage, allowing more than 90% of the population across all socioeconomic strata to access these services in less than 5 minutes of travel. This homogeneous coverage reflects an adequate territorial distribution of this type of facility within the urban area. For recreational facilities, a similar level of population coverage is achieved at the 5-minute threshold; however, a less pronounced growth slope is identified in strata 1 and 6, suggesting a slight relative disadvantage at both ends of the socioeconomic spectrum.

With respect to health facilities, a significant disparity is observed: while the intermediate strata mostly access these services within short travel times, stratum 1 requires up to 7.5 minutes to reach 90% coverage. Additionally, stratum 5 shows a delay, achieving 100% coverage only after 12.5 minutes, which highlights gaps in the location of these services for certain population groups. Finally, security facilities present the lowest relative coverage, especially for strata 1, 2, and 6, which require up to 7.5 minutes to reach 90% coverage. Nevertheless, these values remain below the travel times observed in intermediate cities such as Manizales (Escobar et al., 2015), indicating an acceptable performance in the national context, although still subject to improvement through more equitable and efficient location strategies

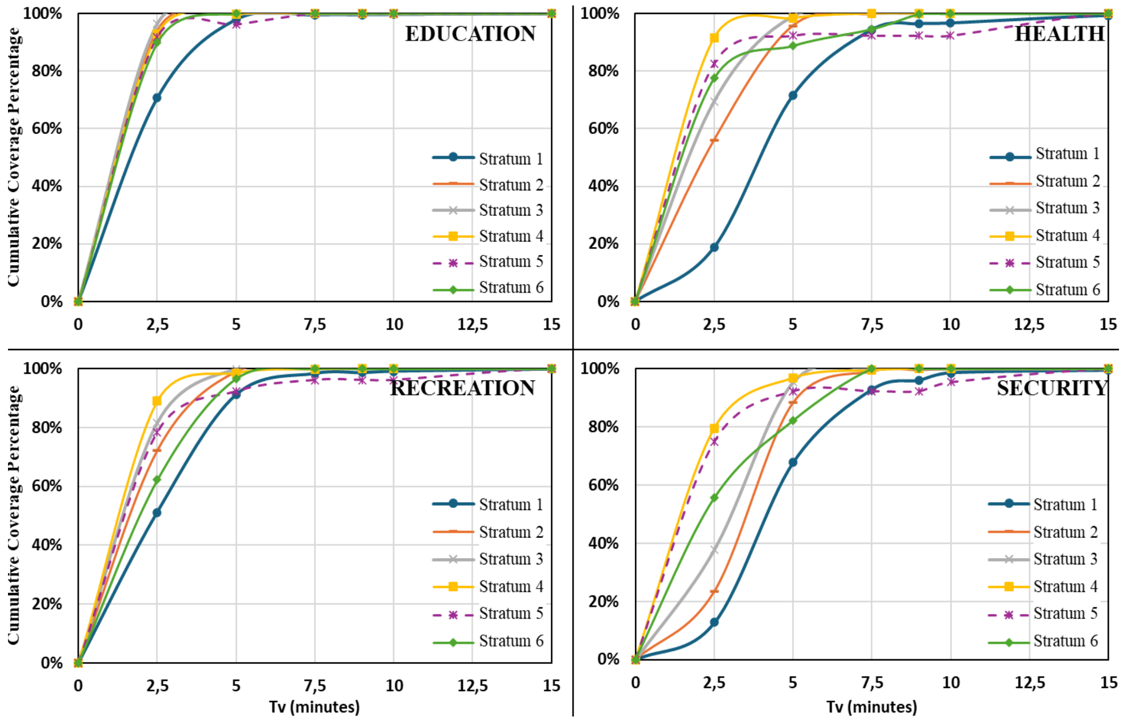

Figure 3. Cumulative Population Coverage Curves for the Primary Activity Nodes of Buenaventura (Source: Authors)

Continuing with the analysis of geographic accessibility, and leaving aside the results obtained for Buenaventura, Figure 4 presents the average travel times required to access primary activity nodes in the city of Cartagena de Indias. This cartographic representation, constructed through isochrone maps, allows for the observation of the spatial distribution of access to different types of urban facilities, using a color scale that facilitates the interpretation of accessibility conditions across the territory.First, it is noteworthy that educational facilities display excellent spatial coverage, similar to what was observed in Buenaventura, enabling access from most of the urban territory in less than 5 minutes. This pattern reflects an adequate location of these services in relation to population distribution. Regarding health facilities, although generalized access is recorded within travel times under 7.5 minutes, certain areas show lower relative coverage, particularly in the southern and northeastern sectors of the city, where travel times exceed the 7.5-minute threshold. Likewise, greater spatial fragmentation is evident in the distribution of these services, with a significant presence of limited-coverage pockets, indicating a need to improve the proximity and territorial distribution of health centers.

With respect to recreational facilities, favorable access is observed for most of the population, with travel times under 5 minutes in central areas. However, specific sectors within the municipality, as well as areas located toward the southern and eastern edges, register travel times exceeding 9 minutes, revealing gaps in the provision of public recreational spaces, particularly in areas of urban expansion or recent densification. Finally, security facilities exhibit the most critical accessibility conditions within the analysis. It is evident that for large areas in the south of Cartagena, as well as other peripheral sectors, travel times to access these services exceed 10 minutes, which represents a potential risk in emergency situations and limits the fulfillment of the principle of territorial equity in the provision of institutional infrastructure.

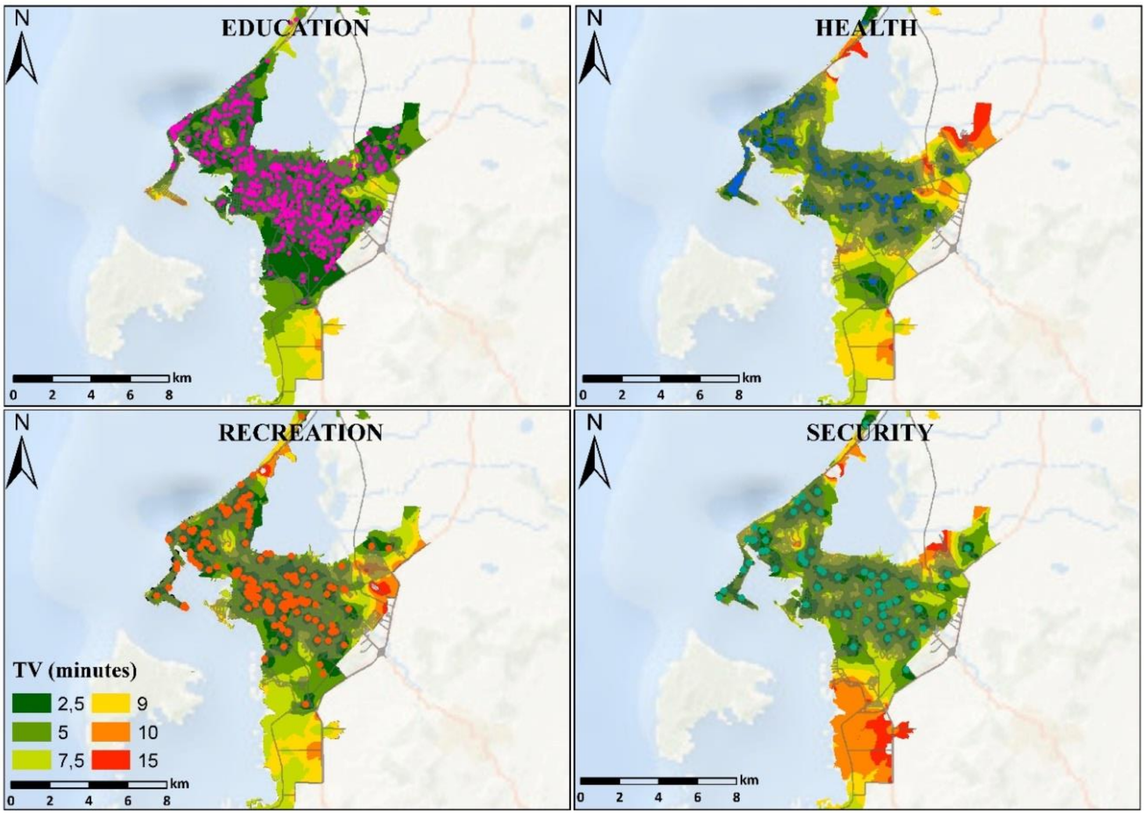

Figure 4. Geographic Accessibility Curves to the Primary Facilities of Cartagena (Source: Authors)

From a technical perspective, the sociodemographic coverage assessment presented in Figure 5 shows differentiated patterns depending on the type of facility and the socioeconomic stratum of the population in Cartagena.

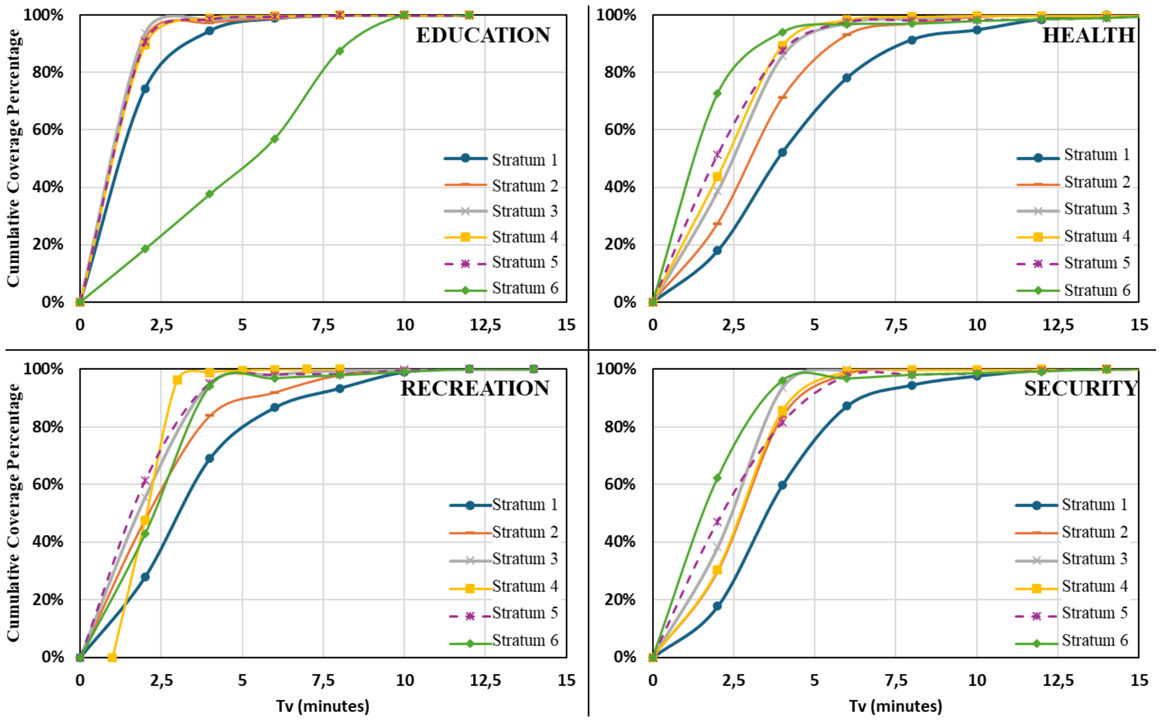

Figure 5. Cumulative Population Coverage Curves for the Primary Activity Nodes of Cartagena (Source: Authors)

Regarding educational facilities, a highly efficient performance is observed, reaching 90% coverage within a travel time of less than 2.5 minutes for strata 2, 3, 4, and 5, which reflects an adequate location of educational infrastructure in medium-density areas. Stratum 1 requires up to 5 minutes to achieve the same level of coverage, which does not represent a critical barrier, although it suggests areas with room for improvement. In contrast, stratum 6 requires travel times exceeding 7.5 minutes, possibly due to its location in peripheral or less-integrated urban sectors. For health facilities, strata 3 to 6 achieve 90% coverage in under 5 minutes, while strata 1 and 2 require slightly longer times, though not exceeding 7.5 minutes. This is considered acceptable but indicative of the need for a more equitable redistribution of health services.

With respect to recreational facilities, all strata—except stratum 1—achieve 90% coverage in less than 5 minutes. Stratum 1 requires an estimated 6 minutes, which, while not representing significant exclusion, indicates lower proximity to these types of public spaces. Finally, security facilities reach 90% coverage within less than 5 minutes for all strata, except again for stratum 1, which requires slightly more than 6 minutes. Although this value is not considered critical in absolute terms, it suggests a lower density or less strategic distribution of these services in areas of greater social vulnerability.

Overall, the results reflect good performance in terms of coverage for most services, although it is necessary to strengthen access for the population in stratum 1—particularly in health, recreation, and security—in order to guarantee greater territorial equity in access to basic urban services. From a comparative perspective between the accessibility conditions to primary facilities in Cartagena and Buenaventura, Table 2 presents the travel times weighted by population, differentiated by type of facility and socioeconomic stratum. This analysis allows for a more precise identification of the relative advantages in urban coverage between the two port cities. In the case of stratum 1, weighted travel times are higher in Buenaventura compared to Cartagena, with the exception of access to recreational facilities, where Buenaventura shows a slight advantage of 0.45 minutes. This pattern indicates a general disadvantage in accessibility for the most vulnerable population in Buenaventura, despite the city having a smaller total population in that stratum.

For strata 2 and 3, the results are more variable. Buenaventura shows better accessibility indicators for health and recreational facilities, while Cartagena maintains advantages in education and security. However, it is essential to note that Cartagena has a significantly larger population—up to seven times greater in certain strata—which places greater pressure on infrastructure. Even so, it manages to maintain favorable levels of accessibility, reflecting a stronger structural capacity and service coverage network. In stratum 4, Buenaventura offers better access times for most services, with values below 3.2 minutes, except in education, where it lags behind Cartagena by 0.45 minutes. In strata 5 and 6, Cartagena demonstrates a sustained advantage, reflecting greater coverage for middle- and high-income sectors. This also suggests a significant structural difference, as Buenaventura has a smaller population representation in these strata, limiting both demand and, consequently, the supply of services for these groups.

Overall, Cartagena demonstrates greater efficiency in population coverage, achieving lower weighted travel times for a considerably larger population. However, Buenaventura, with lower density and urban extension, maintains competitive accessibility levels, revealing a reasonable distribution of its primary facilities, adjusted to its territorial and demographic scale.

Finally, it is worth noting that, in both cities, weighted travel times remain mostly below 5 minutes, representing a positive level of accessibility from an urban planning perspective. This finding suggests that, while structural differences exist between Cartagena and Buenaventura, both cities achieve adequate standards in the provision of basic services, ensuring reasonable mobility toward primary activity nodes for their respective populations

Table 2. Travel times weighted by facilities and socioeconomic status (Source: Authors)

Item	Cartagena	Buenaventura	Cartagena	Buenaventura	Cartagena	Buenaventura
Stratum	1		2		3	
People	431.591	179.037	295.551	41.250	150.131	30.425
Households	123.018	49.069	80.237	12.293	43.768	9.624
Peop./Hous.	3,51	3,65	3,68	3,36	3,43	3,16
Tv. health	5,33	5,56	4,23	3,71	3,59	3,29
Tv. security	4,87	5,73	3,78	4,72	3,38	4,17
Tv. recreational	4,48	4,03	3,56	3,22	3,04	2,97
Tv. Educational	2,64	3,30	2,24	2,65	2,17	2,59
Item	Cartagena	Buenaventura	Cartagena	Buenaventura	Cartagena	Buenaventura
Stratum	4		5		6	
People	37.614	1.313	15.811	57	10.592	32
Households	11.888	523	5.274	31	3.859	11
Peop./Hous.	3,16	2,51	3,00	1,85	2,75	2,96
Tv. health	3,39	2,75	3,38	3,70	2,87	3,42
Tv. security	3,70	3,10	3,55	3,74	2,99	4,06
Tv. recreational	3,16	2,81	2,96	3,52	3,38	3,53
Tv. Educational	2,23	2,68	2,22	2,80	5,99	2,75

CONCLUSION

Based on the analysis conducted, it is possible to conclude that Cartagena demonstrates greater urban consolidation in terms of accessibility, with more homogeneous territorial coverage and lower weighted travel times for most socioeconomic strata and types of facilities. This advantage is supported by better road connectivity and a higher density of facilities—particularly in health, education, and security—reflecting a more developed urban planning structure.

Buenaventura, although with a smaller population and urban scale, exhibits a relatively efficient distribution of its primary facilities, achieving adequate levels of accessibility for lower strata (1, 2, and 3). This suggests that, while its infrastructure is less extensive, the urban territory is being reasonably utilized to meet basic needs.

The direct comparison between cities shows that Cartagena has a greater capacity to respond to population demand, thanks to a denser and more diversified road infrastructure. Nevertheless, Buenaventura demonstrates relative efficiency in service coverage, particularly in recreation, which should be strengthened through planned interventions in mobility and public service provision. The analysis highlights the importance of incorporating equity criteria into territorial planning, integrating both geographic and socioeconomic accessibility assessments to ensure that the entire population can access basic services under similar conditions, regardless of location or income level.

Weighted average travel times by population remain within adequate ranges (generally below 5 minutes) in both cities, indicating that spatial access to facilities does not represent a critical barrier in general terms. However, continued efforts are needed in the siting of activity nodes to achieve greater spatial equity.

The peripheral location of higher socioeconomic strata in Cartagena (e.g., stratum 6) limits their efficient access to certain services, suggesting the need to review the placement of new facilities in response to recent urban growth.

Finally, the use of analytical tools such as isochrone curves, combined with weighting by socioeconomic stratum and facility type, provides highly valuable technical input for evidence-based public policy formulation. These methodologies make it possible to geographically pinpoint accessibility gaps, revealing areas with deficient coverage or excessive travel times for the most vulnerable populations. In turn, this approach allows for prioritization of urban infrastructure interventions using equity-based criteria, maximizing the social impact of public investment. In the context of intermediate and port cities such as Cartagena and Buenaventura—where urban dynamics are intertwined with strategic economic processes and deep socio-spatial inequalities—this type of analysis significantly contributes to fostering more inclusive, resilient, and efficient territorial planning. Moreover, it enables the establishment of simulation and monitoring scenarios that facilitate both ex-ante and ex-post evaluation of urban development policies, thereby strengthening institutional management capacity and promoting a fairer distribution of urban opportunities

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